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REPORT NO 5-95

EVALUATION OF MAKO BAMO6 HIGH PRESSURE BREATHING AIR COMPRESSOR

GEORGE D. SULLIVAN April 1994

NAVY EXPERIMENTAL DIVING UNIT





DITC QUALITY INSPECTED 5



DEPARTMENT OF THE NAVY NAVY EXPERIMENTAL DIVING UNIT

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Approved for public release; distribution unlimited

Submitted by:

G. D. SULLIVAN

GS-11

Test Director

Reviewed by:

R. I. JOHNSTON

GM-13

Hyperbaric Engineer

R.W. MAZZONE

LCDR, USN

Senior Projects

Officer

) R. CLARKE

GM-15

Scientific Director

J.C. MELSON LCDR, USN

Executive Officer

Approved by:

BERT MARSH

CDR, USN

Commanding Officer

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I. INTRODUCTION

In response to NAVSEA tasking¹⁻², a MAKO HIGH PRESSURE AIR COMPRESSOR, MODEL BAMO6, ELECTRIC DRIVE was tested³ by Navy Experimental Diving Unit (NEDU). The purpose of the test was to:

- A. Determine if the compressor and purification system provides compressed air at the required pressures, flow rates, quality and cleanliness required by the U.S. Navy⁴.
- B. Determine the adequacy of the manufacturer's information, instructions and guidance for the safe operation and overall management of the compressor.
- C. Ensure that the compressor purification system discharged clean breathing air required by the U.S. Navy⁴.

II. EQUIPMENT DESCRIPTION

A. GENERAL

The MAKO, MODEL BAMO6 high pressure, breathing air compressor (Figure 1) is of a four stage, four cylinder, "vee" configuration. All first, second, and third stage cylinder bearings are oil mist lubricated (Figure 2). The fourth stage piston is forced oil lubricated via an oil pump and oil pressure regulator. The compressor requires approximately 1.4 liters (2.5 pints) of lubricating oil.

The MAKO compressor unit consists of a compressor block, MK-2-C purification system, auto drain monitoring system, and a drive motor mounted in a compressor module (Figure 3 and 4). The drive unit for this test was a 460 Volt, 3 Phase, 10 Horsepower motor, number M3312T. It is equipped with a hinged motor plate and banded-belt pulley. Rotational torque is transferred to the compressor by a single banded-belt. Electric motors purchased for use with this compressor shall comply with Navy standards for sealed insulation units⁵.

The purification system consists of an interstage separator, auto drain system, auto drain muffler/reservoir, and a MK-2-C central filter with replaceable cartridge. The interstage separators are installed between the 2nd and 3rd, and the 3rd and 4th stages. Internal operation of the interstage separators is through a nozzle which separates water and oil from the compressed air. The interfilter requires routine maintenance (periodic draining).

The auto drain system blows down the separators at 15 minute intervals. This is accomplished by an electric timer which deactivates a solenoid valve that controls the pressure on a bank of piston type valves isolating the separators from the reservoir. The purification system consists of one cartridge chamber. Residual oil and water vapors not drained by the

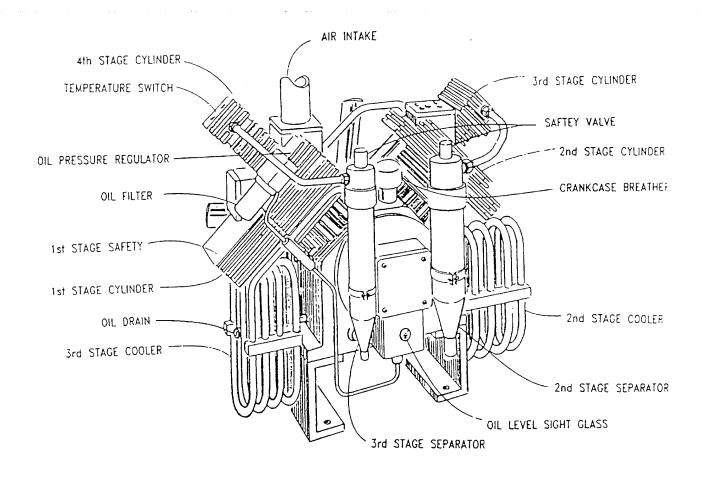


Figure 1 BAMO6 High Pressure Air Compressor

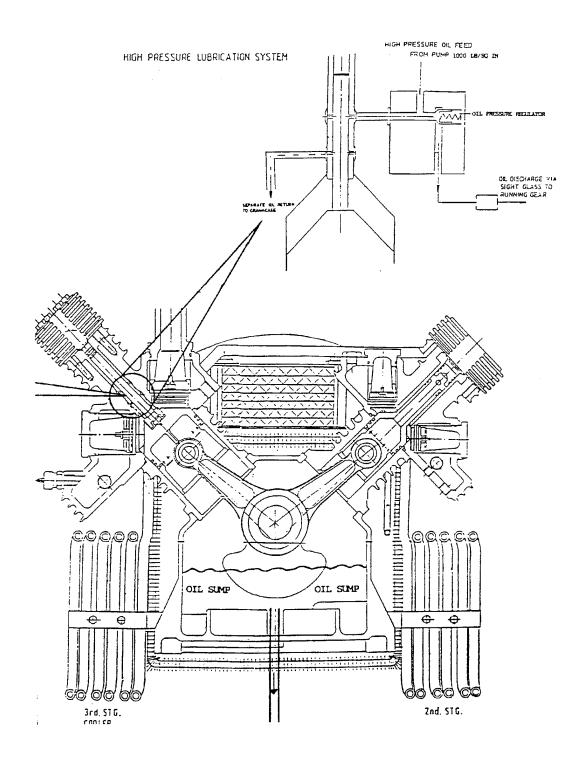


Figure 2 BAMO6 Oil Flow Diagram

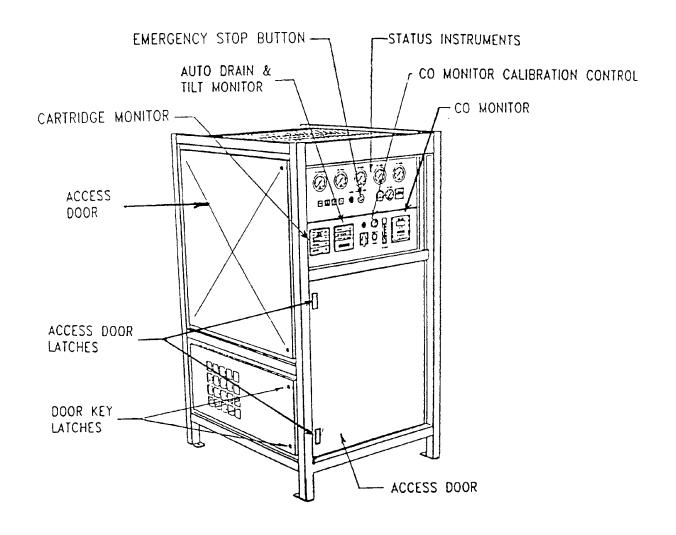


Figure 3 BAMO6 Cabinet Features

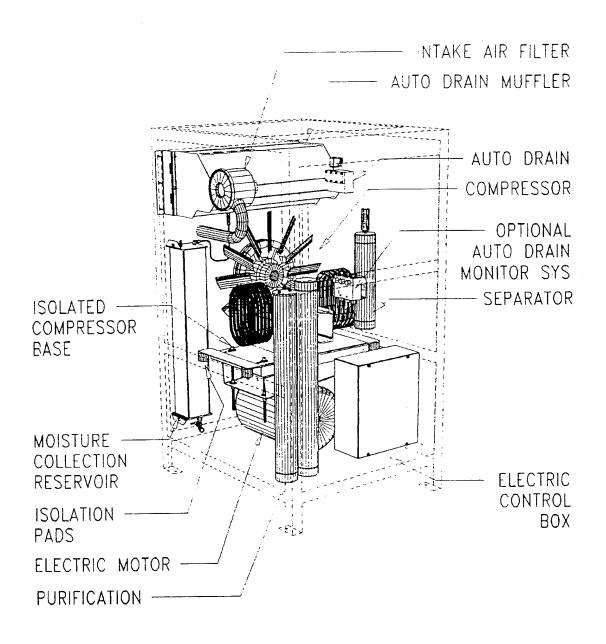


Figure 4 BAMO6 Major Components

auto-drain system are removed by the filter cartridge. The treated air is free of oil, taste and smell. Carbon monoxide is eliminated when a MAKO filter PART No. PD1803 is used.

The MAKO BAMO6 compressor has a rated capacity of 340 liters per minute (12 scfm) free air delivered at 348 bars (5,000 psi) with 31 hours of use per cartridge, when operating at 26.6°C (80°F) or less. The Technical Manual⁶ states:

"Lower pressure or higher temperature will reduce the cartridge life".

A pressure maintaining/non-return valve set at 138 bars (2,000 psi) is provided down-stream from the purification system. This ensures that pressure build-up occurs in the filters during start up and initial compressor air delivery. This achieves constant, optimum filtering, moisture separation, fourth stage piston ring expansion/cylinder sealing, and prevents compressed air return from the storage flasks to the compressor during unit shut down. All four stages of the compressor are protected by safety relief valves. Figure 5 provides a diagram of the compressor air flow/purification system. The compressor comes with an inline carbon monoxide/moisture indicator located in the final pressure service line.

The MAKO, MODEL BAMO6 comes with one Breathing Air Module Owner's Manual⁶ which is divided into the following sections;

- 1. General Description
- 2. Main Components
- 3. Instrumentation and Controls
- 4. Electric System
- 5. Installation and Start-up Procedures
- 6. BAM Operating Procedures
- 7. Maintenance Procedures
- 8. Trouble Diagnosis
- 9. BAM Options

III. TEST PROCEDURE

There are various methods of testing compressor capacities, stability, and reliability. For this compressor evaluation³, NEDU chose to continuously run the compressor for extended periods charging an 89.2 liter (3.15 cuft) cylinder from 0 bars to 345 bars (0 to 5,000 psig).

The compressor and all ancillary equipment was received and set up as per manufacturer's instructions. A Cole Palmer Model 8502-14 temperature monitor and Yellow Springs Instruments 700 Series thermistor probes were attached for measuring compressor discharge and ambient temperatures. An Analox carbon monoxide monitor was used to analyze compressor discharge air both before and after the filter purification system with the sample flow rate set at 300 ml per minute.

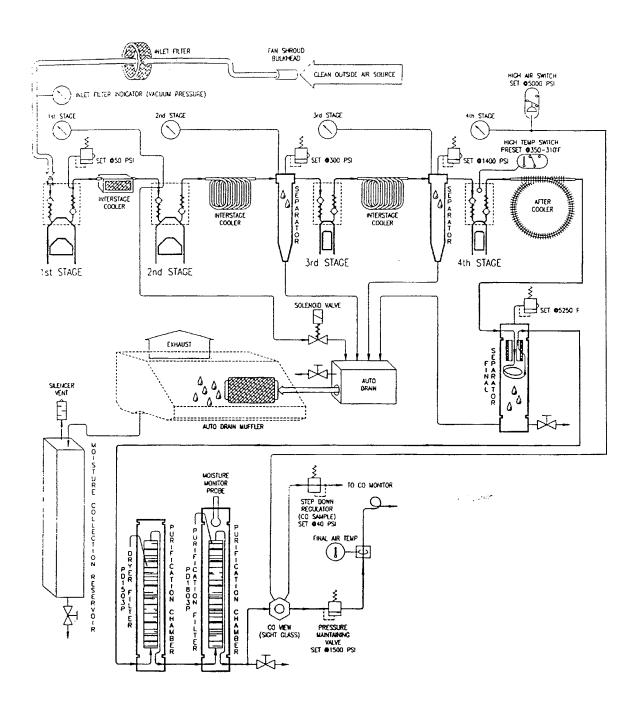


Figure 5 BAMO6 Air Flow Schematic

Nitrogen with a 50.8 PPM mixture of carbon monoxide was used to calibrate the high range of the monitor, and ambient air was used to set the monitor's low range at 0.

A gas mixture of 24.4% carbon monoxide and 75.6% nitrogen was injected into the compressor intake by a Victor Equipment Company manual regulator through a Fisher/Porter flow meter. Figure 6 provides a diagram of the test equipment configuration.

The introduction of carbon monoxide was adjusted to maintain approximately 50 PPM of carbon monoxide at the inlet to the central purification system. Appendix A shows the recorded data from the Test Log. The unit was operated in an exterior work area, open to ambient temperature and humidity. The testing included subjective evaluation of the system operation but did not include detailed mechanical review of the individual components of the system.

The compressor was operated using one purification/filter cartridge. A total of 50 test hours were expended. The following parameters were recorded:

- 1. Date
- 2. Time
- 3. Meter Test Hours
- 4. Ambient Temperature
- 5. Compressor Air Discharge Temperature
- 6. Ambient Humidity
- 7. Carbon Monoxide PPM (Before/After Filtration)
- 8. Injected Carbon Monoxide Flow Rate and Percentage
- 9. Compressor Oil Pressure
- 10. Compressor Final Discharge Pressure
- 11. Cylinder Charging Time
- 12. Compressor Free Air Capacity Flow Rate

Appendix A is recorded data from the Test Log.

IV. OBSERVATIONS/RECOMMENDATIONS

A. AIR DELIVERY

Compressor capacity was determined to be 344 liters per minute (12cfm) by calculating the average time to charge an 89.2 liter (3.15 cuft) floodable volume cylinder from 0 to 345 bars (0 to 5,000 psig). The results of the time required to fill a known volume are recorded in Appendix A.

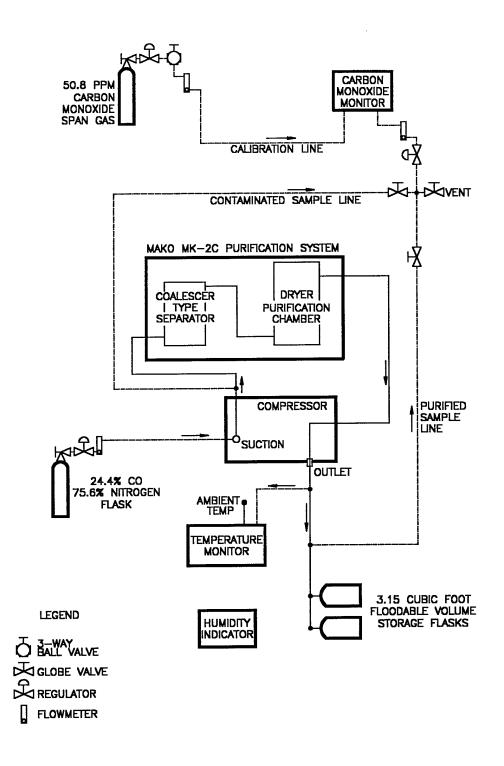


FIGURE 6 NEDU TEST NO. 94-07 CONFIGURATION

B. AIR SAMPLING

Air samples were taken from the compressor purification system discharge at the 1, 35, and 50 hour running time. The samples were sent to the Coastal System Station (CSS) Laboratory, Code 5130, for purity analysis. Analysis of air samples are listed in Appendix B.

C. OIL LUBRICATION

At the beginning of the test, the compressor oil sump level indicated full. Oil level was checked every 30 minutes using the oil level sight glass. Oil consumption was logged in Appendix A. The oil used during the test was MAKO mineral compressor oil. During the 50 hours, a total of 0.24 liters (1/2 pint) of oil was added to the compressor.

D. MAINTENANCE

The Manufacturer's Technical Manual⁶ was easy to read and technically correct. After the first 25 hours running time the following maintenance was performed:

- a. Drained crankcase and refilled with recommended MAKO mineral oil.
- b. Checked drive belt alignment and tension.
- c. Checked tightness of all nuts and bolts.

E. PRIME MOVER

To meet Navy specifications the prime mover, if electric, should be a sealed insulation system (service A use) in accordance with MIL-M-17060 E, Amendment 1.

F. CADMIUM FITTINGS

General Specifications⁷ state that cadmium coated fittings cannot be used in systems that exceed 400 degrees Fahrenheit or if the cadmium could come in contact with petroleum products. At this time the only authorized HP compressor lubricant by the Navy is 2190-TEP (a petroleum based product). Recommend cadmium coated fittings be replaced with stainless steel fittings.

V. CONCLUSIONS

- A. The high pressure air compressor delivers air which meets U.S. Navy standards⁴ at an average rate of 344 liters per minute (12 cfm) per Appendix A. This meets the manufacturer's specification.
- B. The unit is sturdy, reliable and readily maintained.
- C. The purchaser must request the manufacturer to replace all cadmium fittings with stainless steel fittings.
- D. The purchaser must request the manufacturer to provide a "service a use" (MIL-M-17060 E) prime mover if the unit is to be subjected to weather.
- E. The purification cartridge exceeded the manufacturer's specifications.
- F. Based on the results of testing, the MAKO BAMO6 high pressure air compressor system using stainless steel fittings is recommended for inclusion on the Authorized for Navy Use List⁸.
- G The vendor and NAVSEA must be contacted prior to purchase to ensure the unit meets the user's needs.

VI. REFERENCES

- 1. NAVSEA Task 92-002; <u>Evaluation of Commercially Available Divers Air Compressors</u>. Naval Sea Systems Command, 1992
- 2. NAVSEA Task 92-003; <u>Evaluation of Commercially Available Filters for H.P. and L.P. Breathing Air</u>. Naval Sea Systems Command, 1992
- 3. <u>Mako BAM06 E-3 Electric Drive High Pressure Air Compressor and Purification System Evaluation At 000 PSIG Test Plan 93.33 (Unmanned) (Limited Distribution), Navy Experimental Diving Unit March 1994.</u>
- 4. NAVSEA 0994-LP-001-9010 U.S. Navy Diving Manual Volume 1, Rev. 3, Para 5.3.2. Air purity standards, and 6.7.2.1. Air Compressors
- 5. Department of Defense MIL-M-17060 E Amendment 1, <u>Sealed Insulated Systems</u>, (Service A Use). Navy specification for compressor power source
- 6. <u>Breathing Air Module (BAMO6) Manual</u>, Mako Compressors, Inc. 1634 SW 17 Street Ocala, Florida 34474 (904) 732-2268
- 7. Naval Sea Systems Command. S9AA-AA-SPN-010/GENSPEC of Jan 19, 1987. General Specifications for Ships of the Navy, Cadmium Fittings
- 8. Naval Sea Systems Command NAVSEAINST 10560.2C <u>Diving Equipment Authorized for U. S. Navy Use</u>

DATE 1 April 1994

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TIME	METER HOURS	TEM	TEMPS °F	AMBI HUMID	CONCEN	CO/PPM CONCENTRATION	INJECTI COMP.	CO INJECTED INTO COMP. INTAKE	CHARGED CYLINDER SIZE	IGED IDER IE	C'CHARGIN	CYLINDER CHARGING INFORMATION	NOTION	CYL FILL TIME		COMPRESSOR CYLINDER STAGES PSI	ESSOR STAGES 1		OIL
		AMBI TEMP°F	COMP DSCHG°F	<i>8</i> ¢	BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START	END TIME	END PSI		1ST	2ND	3RD	4ТН	PSI
0715	0:56	55	55	63	40	,	0.7cc	24	,	1	-	,		,	37	170	710	1,600	1,010
0730	0:84	53	41	8	45	,	0.8cc	24	1			,	,	1	37	170	710	2,200	066
0800	1:33	55	58	57	50	1	0.9cc	24			'	'	,		37	170	720	2,500	066
0830	1:83	55	65	63	50	-1	0.9cc	24	3.15	5,000	0847	,	,	1	38	170	870	3,600	066
0060	2:33	56	42	61	51	2	0.6cc	24	•		,		,		38	170	720	2,100	066
0630	2:84	57	99	99	50	1	0.7cc	24	-	•		,		,	38	170	740	2,700	066
1000	3:35	59	71	60	50	1	0.7cc	24		•		1015	5,000	88:	38	190	006	4,100	066
1025	Secured	•		,	+	,	4	,	•	•			,	,			1	,	,
0710 Che 0715 Star 1025 Secu	0710 Checked oil level (full) 0715 Started compressor testing 1025 Secured compressor testing	full) testing r testing																	

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: 88 minutes. Therefore, the charging rate is: $\frac{89.2 \times 341.5}{68}$ = 346.2 LPM (12.23CPM)

DATE 4 April 1994

TIME ME	METER	TEM	TEMPS °F	AMBI	CONCEN	CONCENTRATION	C INJECTE COMP. 1	CO INJECTED INTO COMP. INTAKE	CHARGE CYLINDI SIZE	CHARGED CYLINDER SIZE	CHARGIN	CYLINDER CHARGING INFORMATION	NOITA	CYL FILL TIME	-	COMPRESSOR CYLINDER STAGES PSI	ESSOR STAGES 1		OIL
		AMBI TEMP°F	COMP DSCHG*F	%	BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START TIME	END TIME	END PSI		TS1	2ND	3RD	4ТН	Ē
0070	3:75	99	42	98	50	0	0.8cc	24	·		,	,	,		35	165	700	2,100	1,000
02.20	4:28	63	29	26	51	0	0.7cc	24	,	'	•		,	,	37	170	720	2,150	086
0800	4:60	2	7.7	56	20	0	0.6cc	24	•	•	,	,	'		38	175	780	2,700	086
0830	5:11	99	27	93	90	0	0.6cc	24	3.15	5,000	0836		,		40	061	940	4,500	086
0060	5:60	\$9	19	76	90	0	0.6cc	24	-	•	·			'	37	170	720	2,100	086
0630	6:10	\$9	7.5	8	20	0	0.6cc	24	_	•		,	,		38	175	780	2,700	086
1000	9:90	19	78	8	50	0	0.6cc	24	-	•		1006	5,000	0 6 :	40	195	096	4,600	980
1030	7:09	89	63	81	50	0	0.6cc	24	_	•	-	1		,	37	170	720	2,100	086
1100	7:60	0,	80	79	48	0	0.6cc	24	,	٠		,	•		38	180	780	2,150	806
1130	8:09	73	83	76	50	0	0.6cc	24	3.15	5,000	1135	,		,	40	180	920	4,300	806
1200	8:59	69	11	9/	50	0	0.6cc	24	,		,			,	37	170	720	2,100	908
1230	60:6	17	98	74	49	0	0.6cc	24	•	-	,	,	,		40	180	008	2,900	806
1300	9:59	73	88	72	90	0	0.6cc	24	•	-		1304	5,000	68:	9	190	086	4,700	808
1330	10:09	7.2	73	74	90	0	0.6cc	24	,		,	,			38	170	720	2,100	086
1400	10:59	73	87	74	20	0	0.6cc	24	,		•	ı		,	38	180	008	2,700	980
1430	11:09	22	68	75	50	0	0.6cc	24	-	•	,	'		-	40	190	086	4,700	980
1500	11:59	73	72	76	90	0	0.6cc	24	·	-					38	170	720	2,100	980
1501	Secured	•	,		,	1		,	'	-			,	-	,			·	'
0655 Che	0655 Checked oil level 0700 Started compressor testing	. testing																	
1501 Sec	1501 Secured compressor testing	or testing																	

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: $\frac{90 + 89}{2} = 89.5$ minutes. Therefore, the charging rate is: $\frac{89.2 \times 341.5}{89.5} = 340.4$ LPM (12.0CFM)

Appendix A-2

DATE 5 April 1994

TIME	METER HOURS	ТЕМ	TEMPS °F	AMBI HUMID	CONCEN	CO/PPM CONCENTRATION	O INJECT COMP.	CO INJECTED INTO COMP. INTAKE	CHARGED CYLINDER SIZE	IARGED LINDER SIZE	CHARGIN	CYLINDER CHARGING INFORMATION	ATION	CYL FILL TIME		COMPRESSOR CYLINDER STAG PSI	COMPRESSOR CYLINDER STAGES PSI		OIL
		AMBI TEMP°F	COMP DSCHG°F	ęe	BEFORE FILTER	AFTER FILTER	FLOW RATE	% CAS	RATED CUFT	RATED PSI	START TIME	END TIME	END PSI		IST	2ND	3RD	4TH	3
0200	11:68	45	56	79	50	0	0.6cc	24	•			-			37	170	720	2,200	1,000
0220	12:18	25	72	85	50	0	0.6cc	24	3.15	5,000	0758	,	,	,	37	180	820	3,200	086
0800	12:68	82	79	84	50	0	0.6cc	24		•	·	-	-		37	170	720	2,100	086
0830	13:19	65	69	23	50	0	0.6cc	24	٠			-	,		37	170	720	2,150	086
0060	13:68	63	74	96	50	0	0.6cc	24	•	-	,	8760	5,000	06:	48	180	800	3,100	086
0630	14:18	65	59	93	49	0	0.6cc	24	•		-	,	,		47	0/1	720	2,100	086
1000	14:68	67	72	88	48	0	0.6cc	24	,	-	•	•	,	,	47	170	720	2,200	086
1030	15:18	68	61	98	49	0	0.6cc	24	3.15	5,000	1058	,			48	180	. 820	3,100	086
1100	15:67	68	08	83	50	0	0.6cc	24			,		,	,	40	200	1,000	5,000	086
1130	16:17	69	73	82	50	0	0.6cc	24	-	-	•	•			37	170	720	2,100	086
1200	16:67	69	82	82	50	0	0.6cc	24		,	,				38	180	820	3,150	086
1230	17:17	70	83	81	50	0	0.6cc	24	,	,	,	1227	2,000	68:	38	170	720	2,100	086
1231	Secured	,	,	,	•		,	•	,			,		1	1	,		,	
0654 Che 0655 Star 1231 Secu	0654 Checked oil level 0655 Started compressor testing 1231 Secured compressor testing	testing testing																	

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 ps) 341.5 ATA is: $\frac{90 + 89}{2} = 89$, 5 minutes. Therefore, the charging rate is: $\frac{89.2 \times 341.5}{89.5} = 340.4$ LPM (12.0CFM)

Appendix A-3

METER TEMPS "F AMBI CONCENTRATION INJECTED INTO CHARGED CHARGED CHARGING INFORMATION CTLINDER	OIL	PSI PSI	2,100 1,000	2,100 980	
TER TEMPS *F AMBI CONCENTRATION INJECTED INTO CYLINDER CHARGED CYLINDER CYL	OR 'AGES		\vdash	\dashv	
TER TEMPS *F AMBI CONCENTRATION INJECTED INTO CYLINDER CHARGED CYLINDER CYL	COMPRESS LINDER ST PSI		\vdash	-	
TER TEMPS °F AMBI CONCENTRATION COMP. INJECTED INTO CYLINDER CHARGED CYLINDER CHARGED CYLINDER CHARGING INFORMATION COMP. INTAKE SIZE SIZE SIZE SIZE SIZE SIZE SIZE SIZ	CY			_	-
TER TEMPS °F HUMID CONCENTRATION INJECTED INTO CYLINDER CHARGED CYLINDER CHARGED INTO CYLINDER CHARGED INTO CYLINDER CHARGED INFORMATION COMP. INTAKE SIZE AMBI COMP BEFORE AFTER FLOW GAS RATED RATED START END FILTER RATE FLOW GAS CUFT FILME TIME TIME TIME TIME TIME TIME TIME TI	CYL FILL TIME			,	•
TER TEMPS "F AMBI CONCENTRATION INJECTED INTO CYLINDER OF TEMPS F HUMID SIZE SIZE AMBI COMP BEFORE AFTER FLOW GAS RATED SIZE TEMP" SO 93 50 93 50 0 0.6cc 24	ATION	END PSI			,
TER TEMPS "F AMBI CONCENTRATION INJECTED INTO CYLINDER OF TEMPS F HUMID SIZE SIZE AMBI COMP BEFORE AFTER FLOW GAS RATED SIZE TEMP" SO 93 50 93 50 0 0.6cc 24	YLINDER G INFORM/	END TIME			
TER TEMPS °F AMBI CONCENTRATION INJECTED INTO CYLIN CYLIN COMP. INTAKE SIZ COMP. INTAKE SIZ CHARU CAMPI COMP. INTAKE SIZ CHARU CAMPI COMP. INTAKE SIZ CHARU CAMPI CAMP	CHARGIN	START	,	,	
TER TEMPS °F AMBI CONCENTRATION INJECTED INTO CYLIN CYLIN COMP. INTAKE SIZ COMP. INTAKE SIZ CHARU COMP. INTAKE SIZ CHARU COMP. INTAKE SIZ CHARU SI	JED DER E	RATED PSI			,
TER TEMPS °F AMBI CONCENTRATION URS AMBI COMP BEFORE AFTER FI TEMP°F DSCHG°F FILTER FILTER R 1:18 69 50 93 50 0 0 1:67 70 70 100 50 0 0	CHAR(CYLIN SIZ	RATED	,	'	
TER TEMPS °F AMBI CONCENTRATION URS AMBI COMP BEFORE AFTER FI TEMP°F DSCHG°F FILTER FILTER R 1:18 69 50 93 50 0 0 1:67 70 70 100 50 0 0	D INTO	GAS %	24	24	•
TER TEMPS °F AMBI CONCENTR. URS AMBI COMP % AMBI COMP % TEMP°F DSCHG°F FILTER 1:18 69 50 93 50 1:67 70 70 100 50	COMP. I	FLOW RATE	0.6cc	0.6cc	,
TER TEMPS °F AMBI COMP %F HUMID %F FII FII EMP°F DSCHG°F FII FII FII FII FII FII FII FII FII F	PPM TRATION	AFTER FILTER	0	0	•
TER TEMPS °F URS AMBI COMP TEMP°F DSCHG°F 3:18 69 50 5:67 70 70	CONCEN	BEFORE FILTER	50	50	•
URS TEMPE AMBI TEMP°F TEMP°F 70 70	AMBI HUMID	%	93	100	-
AMB TEMP TEMP 69 69 70 70	PS °F	COMP DSCHG*F	90	70	•
TIME METER HOURS 17:18 0800 17:67	TEM	AMBI TEMP°F	69	70	•
TIME TIME 0730 0800	METER HOURS		17:18	17:67	Secured
S 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	TIME		0730	0800	0820

0725 Checked oil level 0730 Started compressor testing 0820 Secured compressor testing (rain)

DATE 7 April 1994

TIME	METER HOURS	TEN	TEMPS °F	AMBI HUMID	CONCEN	CO/PPM CONCENTRATION	C INJECTI COMP.	CO INJECTED INTO COMP. INTAKE	CHAI CYLII SI	CHARGED CYLINDER SIZE	C	CYLINDER CHARGING INFORMATION	ATION	CYL FILL TIME		CYLINDER STAGES PSI	ESSOR S STAGES		OIL
		AMBI TEMP°F	COMP DSCHG°F	6 %	BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED	RATED PSI	START TIME	END TIME	END		1ST	2ND	3RD	4TH	PSI
0730	18:17	52	59	75	50	0	0.6cc	24	1		¢			,	38	175	09/	2,100	1,000
0800	18:55	56	65	82	20	0	0.6cc	24	•		·		,	,	38	185	880	3,900	086
0830	19:05	53	46	77	20	0	0.6cc	24	-	٠	٠		,		37	170	720	2,100	086
0060	19:55	55	65	74	51	0	0.6cc	24	1				,	,	38	175	760	2,600	086
0630	20:12	55	89	78	45	0	0.6cc	24	3.15	5,000	9860				40	195	096	4,700	086
1000	20:55	56	53	77	47	0	0.7cc	24	-		,			,	37	170	720	2,200	086
1030	21:05	58	68	92	49	0	0.7cc	24	1	,	-	1104	5,000	88:	37	180	800	2,800	086
1100	21:55	59	73	74	49	0	0.7cc	24	,		·		,	,	40	195	086	4,700	086
1130	22:04	63	62	72	50	0	0.7cc	24				,	,		37	170	720	2,100	086
1200	22:54	62	76	70	50	0	0.7cc	24	•	-	-	•			38	180	800	2,700	986
1230	23:04	25	79	70	49	0	0.7cc	24	3.15	5,000	1230	1	1		40	195	096	4,500	086
1300	23:54	99	69	89	48	0	0.7cc	24	-		•	•	,		38	175	720	2,100	086
1330	24:04	29	82	67	49	0	0.7cc	24	•	-	-	1358	5,000	88:	40	180	840	3,100	086
1400	24:53	89	87	25	50	0	0.7cc	24			-	·	,		40	200	1,000	5,000	086
1430	25:04	72	75	62	50	0	0.7cc	24	-	-			,	-	38	175	740	2,200	086
0000																			

0720 Checked compressor oil level 0722 Started compressor testing 1430 Secured compressor testing

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: $\frac{88+88}{2} = 88$ minutes. Therefore, the charging rate is: $\frac{89.2 \times 3341.5}{88} = 346.2 \text{ LPW}$ (12.23.CFM)

Appendix A-5

OIL	Ç.	1,000	1,000	086	086	086	086	086	086	086	086
	4TH	2,200	2,250	3,500	2,100	2,250	3,100	2,100	2,200	3,800	2,400
COMPRESSOR CYLINDER STAGES PSI	3RD	720	720	988	720	740	998	720	760	880	780
CYLINDE	2ND	170	175	180	175	175	185	175	175	961	180
	IST	37	37	40	37	38	40	38	38	40	38
CYL FILL TIME			'		'		88:			'	,
IATION	END PSI		٠				5,000	_	٠	,	
CYLINDER CHARGING INFORMATION	END TIME		,	,	,		1020	'	•	,	ı
CHARGIN	START	,		0852			'	'			
GED DER E	RATED PSI			5,000		,		,		,	
CHARGED CYLINDER SIZE	RATED CUFT	'		3.15	-						1
) D INTO NTAKE	GAS %	24	24	24	24	24	24	24	24	24	24
CO INJECTED INTO COMP. INTAKE	FLOW RATE	0.6cc	0.6cc	0.6cc	0.6cc	0.6cc	0.6cc	0.6cc	0.6cc	0.6cc	0.6cc
PM TRATION	AFTER FILTER	0	0	0	0	0	0	0	0	0	0
CONCENTRATION	BEFORE FILTER	50	50	50	50	49	49	50	50	50	48
AMBI HUMID	1 %	70	%	19	62	70	69	70	69	71	70
ž. Š	COMP DSCHG°F	55	19	72	48	72	77	52	76	83	82
TEMPS °F	AMBI TEMP°F	09	19	62	63	25	19	19	69	70	112
METER		25:05	25:19	25:70	26:19	26:70	27:19	27:68	28:18	28:70	29:18
ТІМЕ		0520	00800	0830	0060	0630	1000	1030	1100	1130	1200

Changed compressor oil using MAKO supplied oil (25 hour maintenance) 0750 Started compressor testing 1205 Secured compressor testing

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: 88 minutes. Therefore, the charging rate is: 89.2 X 341.5 = 346.2 LPM (12.23 CFM)

DATE 11 April 1994

OIL	PSI	1,000	086	086	086	
	4ТН	2,250	3,200	2,100	3,000	
COMPRESSOR CYLINDER STAGES PSI	3RD	720	840	740	780	
CYLINDE P	2ND	170	185	175	180	
	IST	37	38	38	38	
CYL FILL TIME						
ATION	END		-	,	-	
CYLINDER CHARGING INFORMATION	END TIME	•	-	-		
CHARGIN	START	•			,	
GED IDER JE	RATED S PSI		-			
CHARGED CYLINDER SIZE	RATED CUFT			-	-	
CO INJECTED INTO COMP. INTAKE	GAS %	24	24	24	24	
COMP. I	FLOW RATE	0.6cc	0.6cc	0.6cc	0.6cc	
CO/PPM CONCENTRATION	AFTER FILTER	0	0	0	0	
CONCENT	BEFORE FILTER	90	95	50	50	
AMBI HUMID	%	86	90	66	100	
TEMPS °F	COMP DSCHG*F	80	86	71	82	
TEMI	AMBI TEMP°F	76	77	77	77	
METER HOURS		29:29	29:61	30:15	30:50	
TIME		0939	1000	1030	1100	

0915 Checked compressor oil 0938 Started compressor testing 1101 Secured compressor testing (rain)

TIME METER AMBI CONDENTRATION CON	אלנו וולט זו חושם	17.77												-						
AMBI COMP % BEFORE FILTER FLATER FLATER RATE	TIME	METER HOURS	TEM	1PS °F	AMBI HUMID	CONCENT	PPM FRATION	INJECTI COMP.	O ED INTO INTAKE	CHAR CYLIN SIZ	GED DER E	C) CHARGINC	ZLINDER 3 INFORMA	TION	CYL FILL TIME		CYLINDER PS	ESSOR STAGES I		OIL PRESS
30.53 72 75 95 50 0.6cc 24 -			AMBI TEMP°F	COMP DSCHG*F	8%	BEFORE FILTER	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START TIME	END	END PSI		ıst	2ND	3RD	4ТН	Ē.
31:05 72 81 81 81 81 81 84 84 84 94	0730	30:53	72	27	95	50	0	0.6cc	24			,	,		,	37	170	720	2,250	1,000
31.48 72 58 99 50 0 0.6cc 24 · · · · · · 37 170 720 2.100	0800	31:05	72	81	86	50	0	0.6cc	24		,		,	,	,	38	180	840	3,400	086
32:07 72 78 100 50 0 0.6cc 24 · · · · 37 170 740 2,250	0830	31:48	72	58	66	50	0	0.6cc	24		,		,		,	37	170	720	2,100	086
	0060	32:07	72	78	100	90	0	0.6cc	24		,	,	,			37	170	740	2,250	086

0725 Checked compressor oil 0729 Started compressor testing 0901 Secured compressor testing (rain)

DATE 15 April 1994

		,		,	,			,		,	 ,			
OIL	PSI	1,000	086	086	086	086	086	086	086	086	086	086	086	
	4ТН	2,800	3,300	2,200	2,200	3,300	4,900	2,200	3,200	2,100	2,200	3,400	2,100	,
COMPRESSOR CYLINDER STAGES PSI	ЗКБ	780	920	720	720	840	1,000	720	820	720	740	840	740	
CYLINDE	2ND	175	190	170	170	180	200	170	180	170	175	180	170	
	1ST	38	40	28	35	38	40	38	38	38	38	38	38	ı
CYL FILL TIME			,	-		-		-			:88			-
ATION	END PSI		•	-	•	•	-	-	-	-	2,000		-	,
CYLINDER CHARGING INFORMATION	END TIME	-		-	-			-	-	-	1154	•	-	-
CHARGIN	START TIME	,	•			•	-	-	1026	-	-	-	-	
JED DER	RATED PSI	-				-	-	-	5,000		-	-	-	-
CHARGED CYLINDER SIZE	RATED CUFT	,	,	,	•			,	3.15		•		•	,
O ID INTO NTAKE	GAS %	24	24	24	24	24	24	24	24	24	24	24	24	-
CO INJECTED INTO COMP. INTAKE	FLOW RATE	0.6cc	0.6cc	0.5cc	0.5cc	0.5cc	-							
PPM FRATION	AFTER FILTER	0	0	0	0	0	0	0	0	0	0	0	0	,
CO/PPM CONCENTRATION	BEFORE FILTER	90	50	50	20	50	90	50	20	95	50	20	05	,
AMBI HUMID	%	95	100	100	98	96	96	95	92	91	90	90	91	
9° ₽°	COMP DSCHG*F	11	83	29	9/	98	88	77	87	70	83	88	70	
TEMPS °F	AMBI TEMP°F	74	74	74	74	74	74	74	91	11	9/	11	11	
METER HOURS		32:34	32:80	33:28	33:52	34:06	34:49	35:02	35:54	35:97	36:53	37:03	37:47	Secured
TIME		0649	00/00	0220	0800	0830	0060	0830	1000	1030	1100	1130	1200	1217

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: 88 minutes. Therefore, the charging rate is: $\frac{89.2 \times 2341.5}{88}$ = 346.2 LPM (12.23CFM)

0645 Checked compressor oil
0649 Started compressor testing
1030 Secured co, injection, cartridge exceeded manufacture's in service life
1217 Secured compressor testing

AMBI COMP 37:80 71 70 38:14 71 75 38:70 73 80 39:08 73 57 40:10 75 82 40:10 75 82 40:72 80 85 41:13 80 90 41:13 80 90 42:07 85 93 42:07 85 93 43:07 86 85 43:07 80 85 44:57 80 96 44:57 81 89	TIME	METER HOURS	TEMI	TEMPS °F	AMBI HUMID	CONCENTRATION	PM 'RATION	C INJECTI COMP.	CO INJECTED INTO COMP. INTAKE	CHAR CYLIN SIZ	CHARGED CYLINDER SIZE	C CHARGIN	CYLINDER CHARGING INFORMATION	ATION	CYL FILL TIME		COMPRESSOR CYLINDER STAGES PSI	ESSOR STAGES		OIL PRESS
38.14 71 70 72			AMBI TEMP°F	COMP DSCHG*F	ъ.	BEFORE	AFTER FILTER	FLOW RATE	GAS %	RATED CUFT	RATED PSI	START	END TIME	END		1ST	2ND	3RD	4ТН	PSI
38.0 73. 73. 73. 73. 73. 73. 73. 73. 73. 73. 73. 73. 73. 73. 73. 73. 73. 73. 73. 74. 73. 74. <td>0730</td> <td>37:80</td> <td>71</td> <td>70</td> <td>72</td> <td>-</td> <td></td> <td>,</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>·</td> <td></td> <td>38</td> <td>175</td> <td>092</td> <td>2,500</td> <td>1,000</td>	0730	37:80	71	70	72	-		,						·		38	175	092	2,500	1,000
39:00 73:00 60 70 <	0800	38:14	17	7.5	72	-	•	-	•	,	,	,	,			38	180	800	2,900	086
39.08 73 57 50 7<	0830	38:70	73	80	62	1	•	-	•		•		,		-	40	840	840	4,200	086
40:10 75 55 3.15 <td>0060</td> <td>39:08</td> <td>73</td> <td>57</td> <td>20</td> <td>,</td> <td>•</td> <td>•</td> <td>•</td> <td>-</td> <td>,</td> <td></td> <td>•</td> <td>'</td> <td></td> <td>38</td> <td>740</td> <td>740</td> <td>2,100</td> <td>086</td>	0060	39:08	73	57	20	,	•	•	•	-	,		•	'		38	740	740	2,100	086
40:10 75 82 60 3.15 5,000 1103 3.15 5,000 1103	0630	39:70	74	75	55	,	-	•	•	•	-		,	٠		38	740	740	2,100	086
40.72 80 85 61	1000	40:10	7.5	82	8	,			1	-	•				,	38	760	760	2,200	086
41:13 80 90 61	1030	40:72	80	85	19	•	٠	•	,	3.15	5,000	1103	,	,		38	810	810	3,000	086
41:70 81 85 93 57	1100	41:13	80	8	19		•	•	,	-		'		•		40	1,000	1,000	2,000	086
42:07 85 93 57 9<	1130	41:70	81	85	65	•		•	1		,		1231	5,000	:88	38	760	760	2,000	086
43.56 88 97 56 80 85 57 9 <th< td=""><td>1200</td><td>42:07</td><td>85</td><td>93</td><td>2.2</td><td>,</td><td>•</td><td>,</td><td></td><td>'</td><td></td><td></td><td></td><td></td><td>-</td><td>40</td><td>840</td><td>840</td><td>2,900</td><td>086</td></th<>	1200	42:07	85	93	2.2	,	•	,		'					-	40	840	840	2,900	086
43.07 80 85 57 80 81 96 81 96 81 96 98 90	1230	42:58	85	26	99	1		,	'	,	,					40	1,000	1,000	4,900	086
43.56 81 96 58 .<	1300	43:07	80	85	57			'			-	,	·			38	760	760	2,200	086
44:05 80 96 59 -<	1330	43:56	81	96	58	1	1	·	•		·					38	86	840	3,000	086
44:57 81 89 59	1400	44:05	80	96	59	-		,	•	,	,	-		,	,	40	200	1,000	5,000	086
Secured 58 97 58 - 38 185	1430	44:57	81	68	59		-	•	•	_	1	,		·		37	175	740	2,200	086
Secured	1500	45:02	82	16	58	•	,	,	,		'					38	185	840	3,100	086
	1501	Secured	,		1	,	,					٠	1	,	-	,	,	,	-	

0725 Checked compressor oil 0730 Started compressor testing 1501 Secured compressor testing

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is: 88 minutes. Therefore, the charging rate is: $\frac{89.2 \times 341.5}{88}$ = 346.2 SLPM (12.23CFM)

DATE 19 April 1994

-																			
TIME	METER HOURS	TEM	TEMPS °F	AMBI HUMID	CO/PPM CONCENTRATION	PM FRATION	C INJECTI COMP. J	CO INJECTED INTO COMP. INTAKE	CHARGED CYLINDER SIZE	IARGED LINDER SIZE	C' CHARGIN	CYLINDER CHARGING INFORMATION	TION	CYL FILL TIME		COMPRESSOR CYLINDER STAGES PSI	ESSOR t STAGES 1		OIL
		AMBI TEMP°F	СОМР DSCHG°F	6 %	BEFORE	AFTER FILTER	FLOW	GAS %	RATED CUFT	RATED PSI	START	END	END		1ST	2ND	3RD	4TH	PSI
0700	45:07	89	89	80	-	-		•	3.15	5,000	0704				38	17.5	780	2,800	1,000
0730	45:62	89	1.9	1.8	•		•			•	,		,	,	38	175	740	2,200	086
0800	46:07	89	78	1.8	•		•	,	,	,			•	,	38	081	008	3,000	086
0830	46:53	69	18	88	٠	•	•		-			0832	5,000	88.	40	200	1,000	4,800	086
0900	47:03	69	7.1	06	•	•				•		•	,		37	175	740	2,100	086
0930	47:55	70	82	26	•	•	•		-	-			•		38	081	820	3,000	086
1000	48:04	72	84	25					3.15	5,000	1002		,	,	40	200	1,000	4,900	086
1030	48:56	71	73	25	-		-	,	-	-	•	•			38	175	740	2,200	086
1100	49:03	72	83	93		-	•		1		1				38	180	820	3,000	086
1130	49:53	74	88	85	-	•	•	,	•	•	•	1130	5,000	88:	40	200	1,000	5,000	086
1200	50:04	75	76	8	-	•	•	•	•	-					38	175	740	2,100	086
1205	•	٠	•	,			-		•	•						,			
0655 Char	1655 Charked compression	ļ.																	

0655 Checked compressor oil
0700 Started compressor testing
1205 Secured compressor testing 50 hours
Added 0.23 liters (1/2 pitt) compressor oil during 50 hour test

The mean time for pressurizing an 89.2 liter (3.15cuft) flask from 0 to 345 bars (0 to 5,000 psi) 341.5 ATA is:

APPENDIX A - TEST LOG

 $\frac{\theta\theta + \theta\theta}{2} = \theta\theta$ mirutes. Therefore, the charging rate is:

89.2 X 341.5 = 346.2 LPM (12.23CFM)

Appendix A-11

To: Dave Sullivan, NEDU

From: Glen Deason, Code 2530

Subject: Analysis of air sample from NEDU Test #94-07.

Mako Bam 06 evaluation. Fifty hour sample.

1. In accordance with your request, the air sample delivered to the gas analysis lab was analyzed and found to contain:

Standard Components

Component	Level	Limit
Oxygen	21%	20-22%
Nitrogen	78.1%	NONE
Argon	0.9%	NONE
Carbon Dioxide	340 PPM	1000 PPM
Total Hydrocarbons 1	1.6 PPM	25 PPM
Carbon Monoxide	<0.5 PPM	20 PPM
Methane	1.6 PPM	1000 PPM
Acetone	<0.1 PPM	200 PPM
Benzene	<0.1 PPM	1 PPM
Chloroform	<0.1 PPM	1 PPM
Ethanol	<0.1 PPM	100 PPM
Freon 113	<0.1 PPM	100 PPM
Freon 11	<0.1 PPM	100 PPM
Freon 12	<0.1 PPM	100 PPM
Freon 114	<0.1 PPM	100 PPM
Isopropyl Alcohol	<0.1 PPM	1 PPM
Methanol	<0.1 PPM	10 PPM
Methyl Chloroform	<0.1 PPM	30 PPM
Methyl Ethyl Ketone	<0.1 PPM	20 PPM
Methyl Isobutyl Ketone	<0.1 PPM	20 PPM
Methylene Chloride	<0.1 PPM	25 PPM
Toluene	<0.1 PPM	20 PPM
Trimethyl Benzenes	<0.1 PPM	3 PPM
Xylenes	<0.1 PPM	50 PPM

<u>ot</u>

Limit Level Component

NONE

<0.1 PPM NONE C4+

1Expressed as methane equivalents.
2Limits taken from Navy Dive Manual; Vol. 2, Rev. 3.
3OSHA Final Rule limits published as of July 1992 (not specified in Navy Dive Manual).

2. The above sample showed no appreciable contamination; all components were within the acceptable range.

Glen Deason Chemist To: Dave Sullivan, NEDU

From: Glen Deason, Code 2530

Subject: Analysis of air sample marked Mako Bam06 Evaluation. 1

Hour Sample. Test # 94.07.

1. In accordance with your request, the air sample delivered to the gas analysis lab was analyzed and found to contain:

Standard Components

Component	Level	Limit
Oxygen Nitrogen Argon Carbon Dioxide	21% 78.1% 0.9% 113 PPM	20-22% ² NONE ² NONE ² 1000 PPM ²
Total Hydrocarbons ¹ Carbon Monoxide Methane	1.5 PPM <0.5 PPM 1.5 PPM	25 PPM ² 20 PPM ² 1000 PPM ²
Acetone Benzene Chloroform Ethanol Freon 113 Freon 11 Freon 12 Freon 114 Isopropyl Alcohol Methanol Methyl Chloroform Methyl Ethyl Ketone Methyl Isobutyl Ketone Methylene Chloride Toluene Trimethyl Benzenes	<0.1 PPM	200 PPM ² 1 PPM ² 1 PPM ² 1 PPM ² 100 PPM ² 20 PPM ² 20 PPM ² 20 PPM ² 20 PPM ² 21 PPM ² 22 PPM ² 23 PPM ² 24 PPM ² 25 PPM ² 26 PPM ² 27 PPM ² 28 PPM ² 29 PPM ² 21 PPM ² 21 PPM ² 22 PPM ² 23 PPM ² 24 PPM ² 25 PPM ² 26 PPM ² 27 PPM ² 28 PPM ² 29 PPM ²
Xylenes	<0.1 PPM	50 PPM ²

Other Components

Component Level Limit

NONE

C4+ <0.1 PPM NONE

¹Expressed as methane equivalents. ²Limits taken from Navy Dive Manual; Vol. 2, Rev. 3. ³OSHA Final Rule limits published as of July 1992 (not specified in Navy Dive Manual).

2. The above sample showed no appreciable contamination; all components were within the acceptable range.

Glen Deason Chemist

Elen Deeson 1452.

To: Dave Sullivan, NEDU

From: Glen Deason, Code 2530

Subject: Analysis of air sample marked Mako BAM06 Evaluation

35 Hour Sample.

1. In accordance with your request, the air sample delivered to the gas analysis lab was analyzed and found to contain:

Standard Components

Component	Level	Limit
Oxygen Nitrogen	21% 78.1%	20-22% ² NONE ²
Argon Carbon Dioxide	0.9%	NONE ²
carbon bloxide	319 PPM	1000 PPM ²
Total Hydrocarbons¹	1.5 PPM	25 PPM ²
Carbon Monoxide	<0.5 PPM	20 PPM^2
Methane	1.5 PPM	1000 PPM ²
Acetone	<0.1 PPM	200 PPM ²
Benzene	<0.1 PPM	1 PPM^2
Chloroform	<0.1 PPM	1 PPM ²
Ethanol	<0.1 PPM	100 PPM^2
Freon 113	<0.1 PPM	100 PPM^2
Freon 11	<0.1 PPM	100 PPM ²
Freon 12	<0.1 PPM	100 PPM ²
Freon 114	<0.1 PPM	100 PPM ²
Isopropyl Alcohol	<0.1 PPM	1 PPM ²
Methanol	<0.1 PPM	10 PPM ²
Methyl Chloroform	<0.1 PPM	30 PPM ²
Methyl Ethyl Ketone	<0.1 PPM	20 PPM ²
Methyl Isobutyl Ketone	<0.1 PPM	20 PPM ²
Methylene Chloride	<0.1 PPM	25 PPM²
Toluene	<0.1 PPM	20 PPM²
Trimethyl Benzenes	<0.1 PPM	3 PPM ²
Xylenes	<0.1 PPM	50 PPM ²
her Components		

Oth

Component Level Limit

NONE

C4+ <0.1 PPM NONE ¹Expressed as methane equivalents.

²Limits taken from Navy Dive Manual; Vol. 2, Rev. 3.

³OSHA Final Rule limits published as of July 1992 (not specified in Navy Dive Manual).

2. The above sample showed no appreciable contamination; all components were within the acceptable range.

Glen Deason Chemist